TECHNICAL REFERENCE DOCUMENT

PROTECT AND MONITOR OUR OCEAN RESOURCES

1. Introduction

Ocean resources include living marine resources such as fish, marine mammals and sea birds, corals, kelp, plankton and algae, and non-living resources such as shoreline, oil and gas reserves, sand, salt and sea water itself. These resources account for a significant portion of the U.S. economy in goods and services; recent estimates for just the coastal areas alone are 28 million jobs, millions in goods and services, and an attractive tourist destination for 180 million Americans every year. The health and availability of these resources affect millions of U.S. citizens, tourists and our bordering neighbors. U.S. coastal areas are among the most developed in the nation, with over half of our population residing within less than one-fifth of the land area in the contiguous U.S. Coastal and ocean management is critically important to the environment, economy and public safety. Our ability to actively observe, protect and sustain U.S. coastal and ocean resources is essential to ensure these societal benefits for future generations.

Fundamental to management of ocean resources is the requirement to balance the need for increasing energy, coastal development, marine transportation and national security demands with preserving healthy and sustainable coastal and marine ecosystems and coastal communities. Critical living ocean resource issues include declining fish stocks, loss of marine mammals, sea turtles, bird species and populations, introduction and proliferation of nonindigenous species, loss of biodiversity, and degradation and restructuring of relevant coastal and marine habitats including water quality. In particular, declining fish stocks pose a threat to global food security and global economies, calling for accurate and timely information about surrounding environmental conditions and status and effects of ecological interactions, from phytoplankton to humans. There is also an increasing need to quantify and predict the effects of climate change, including sea level rise and effects of extreme weather events, on coastal and open ocean resources.

Many U.S. ocean resources are found in the coastal regions (top of the watershed to the Exclusive Economic Zone, or EEZ), some of interest to the U.S. such as migratory sea birds, fish and marine mammals range well beyond U.S. borders. Our coastal waters are contiguous with those of neighboring nations and the ocean waters circulate on a global scale. The physical and biogeochemical variability that influences marine resources off our coasts may originate in international waters. In addition to large scale ocean flows and patterns of variability, there are large scale coupled ocean-atmosphere patterns of variability, in which ocean conditions at locations remote from the U.S. cause our weather and climate to vary. Thus, the U.S. effort to monitor ocean resources must cover both the region out to the EEZ and, in partnership with other nations, the adjacent coastal waters and the global blue water ocean.

To make the most effective decisions for protecting and preserving ocean resources, accurate information from an ocean observing system is required to allow for detection and prediction of the causes and consequences of changes in marine and coastal ecosystems, watersheds and non-living resources. The recommendations of the U.S. Commission on Ocean Policy (2004), lessons learned during the White Water to Blue Water Partnership Initiative (see http://www.state.gov/g/oes/rls/fs/2003/18969.htm) and other reports and studies endorse an ecosystem approach and/or a watershed approach for the ocean observing system. This system should be able to assess and predict phenomena such as impacts of climate change and weather events like coastal storms, natural and man-made hazards such as oil spills and pollution, and other stressors such as fishing, recreational activities, marine transportation, coastal construction and development and ocean drilling/exploration. Observations gathered from ships, aircraft, satellites, drifters, buoys and other remote and *in situ* sensors are needed for a wide range of physical, biological, chemical, geological and atmospheric variables within U.S. coastal regions, islands and territories, and open ocean regions. Coordination of this information obtained at various time and space scales, from periodic sampling to real time observations, and from existing, nascent and planned networks is complex and will demand dedicated resources, commitment and focus to accomplish. Just as important will be the development and implementation of coupled physical-biological (ecological) models, of data assimilation techniques and of products and services that translate available information into rapid and long term assessments, forecasts and decision tools for a wide range of users, supported by a responsive research enterprise. Ongoing evaluation of the efficacy of the observing systems and ongoing guidance of its evolution are needed so that the results of research programs and pilot projects, including new tools, lessons on scales of variability, and new models and data assimilation methods, can be introduced. User input concerning usefulness and improvements of the products and services is also a key part of the system evaluation.

A crucial requirement for an "integrated" ocean observing system is the recognition that there are communities of living organisms that occupy the physical environment and that those communities (including humans) are influenced by the physical environment, and influence each other and the environment by consuming resources. Living resource managers recognize the need for information on environmental processes as these affect the range of consumable and protected species that they seek to maintain for society's benefit. Similarly, the physical oceanographic and climate scientists and managers need to recognize the dependence of ecosystems on physical processes, and seek to understand how they affect the physical-climate system. Addressing both abiotic and biotic information needs will ensure that the observing system addresses both coastal and ocean resource issues and the requirements of ecosystem approach to management.

These ocean resource management requirements call for a sustained, integrated ocean observing system (IOOS) that is robust, rigorous, reliable, responsive and effective. Initial plans for the U.S. contribution to a Global Ocean Observing System, IOOS, have been developed under the umbrella of the National Oceanographic Research Leadership Council (NORLC). NORL established an office, OCEAN.US, to coordinate the development and implementation of IOOS. More details about this structure are found at http://www.nopp.org.

2. User Requirements

User groups

User groups for ocean resource information include a wide range of users with various data and information needs, capabilities and missions, including, but not limited to, federal agencies, state and local governments who have federal laws and mandates to fulfill, the shipping industry, port authorities, law enforcement, public health sector, insurance industry, economic development boards, coastal resource managers, regulatory authorities, non-governmental organizations, tourist industry, coastal engineers, sanitation district officials, emergency managers, research scientists, recreational users, home owners, fishing industry, and the military. Some users are also suppliers of critical ocean information. Users can be coastal managers who make rapid (e.g. beach closures) and long range (e.g. development zoning) decisions on coastal resources, ship captains navigating ports and harbors, wind surfers trying to locate the best currents, oil and gas companies drilling for oil, or researchers developing a new technique to remotely monitor salinity. Detailed lists of users can be found in a variety of recent reports listed in the references, including: the U.S Commission on Ocean Policy (2004); National Ocean Oceanographic Partnership Program/ National Ocean Research Leadership Council (1999 and 2003); Intergovernmental Oceanographic Commission (2000); NOAA et al. (1999); and OCEAN.US (2002).

Information needs

Ocean resource users need a wide variety of information ranging from raw data and data products to assessments, predictions, and decision tools. They need to be able to find the data or information products they need, overlay or compare with other data and products, and translate the information into actions and decisions. Key users need data and information to help predict and mitigate events that affect the marine/watershed environment, as well as related economic interests. Data sets and models are needed for immediate action (e.g. response to an impending HAB), as well as for long term planning (e.g. mitigation of coastal inundation caused by sea-level rise).

High level requirements of these users include:

- improved weather forecasts, climate predictions and information products to help mitigate natural hazards
- assessments of the state and health of marine ecosystems, watersheds and the resources they support
- a sound scientific basis to inform environmental policies that take into account natural and anthropogenic changes in marine ecosystems and the effects of these changes on people.

General information needs include:

- More accurate estimates of inputs of freshwater, sediments, nutrients, organisms and contaminants from all sources into coastal waters;
- Better understanding of how geomorphology and depth govern the response of coastal ecosystems to external forcings
- Improved marine meteorological forecasts, nowcasts, ocean and coastal circulation models
- More timely quantification and detection of environmental trends, such as climate change and coastal population shifts, and their impacts on ecosystems
- Better understanding of ecosystem dynamics and its effect on marine resources
- Better assessments of the impacts of weather and climate change variability and natural and introduced disease, toxins and predation on coastal and blue water ecosystems and communities including fish and shellfish stocks
- Improved seasonal and longer term climate forecasts from coupled models assimilating ocean observations to support better planning of energy use

for heating, cooling, and production of water resources management, and of agriculture

Examples of specific local or regional issues that need to be addressed include nutrient enrichment, oxygen depletion, harmful algal blooms (HABs), chemical contamination, fish kills, habitat loss, shoreline erosion, increasing susceptibility of coastal communities to natural hazards, declines in marine resources, loss of biodiversity, and invasions of non-indigenous species. An ecosystem-based management approach also requires temporal and spatial analyses of data collected by the observing system, to include:

- climatologies, including from paleo-oceanographic data, of core variables (hindcasts and quantification of past natural variability);
- improved nowcasts of the spatial distribution of core variables (fields);
- forecasts of changes in these fields that affect the distribution and abundance of living organisms and the condition of habitats upon which they depend; and
- sites designated as marine protected areas and sentinel/research sites.

Measurement parameters and system components

In order to address these user needs and implement an ecosystem/watershed-based approach to protecting and managing ocean resources, a variety of physical, biological, chemical, geological and atmospheric parameters must be monitored. Such observations are critical inputs into sophisticated models, timely and rapid forecasts, and assessments of the status and trends of marine ecosystems and watersheds. Coverage includes the coastal regions, and of the global ocean in order to address the impacts of remote regions on the U.S. land and ocean, to detect change in critical regions such as the high latitudes, and to monitor, understand, and predict the circulation of the global ocean and its interaction with the atmosphere and land.

An initial list of "core" (required) parameters has been developed for IOOS and is found in Appendix I, along with the federal observing systems which provide these parameters on a routine, sustained basis. Also available in OCEAN.US (2002) are listings of existing or required information products derived from the observing data. These products vary in their level of complexity and detail, ranging from coastal weather map facsimiles, to combined *in situ* and remotely sensed data products, to outputs of sophisticated, coupled physical-ecological models.

Critical components of an integrated ocean observing system include:

- platforms from which observations are made (ships, small boats, aircraft, satellites, and land stations) and the ongoing maintenance, overhauls and replacements needed to sustain this capacity;

- stable, sustained near-real-time data sets from *in situ* and remote sensors;

- operational models (including data assimilation models) that provide outputs in near-real-time;

- robust calibration and validation for all systems (operational, pre-operational, pilot and research), to ensure the accuracy and stability of data inputs and model outputs;

- development of new sensors, techniques, assessment tools, models, and data management and analysis tools;

- processes to transition high value research projects into the operational system;

- skilled personnel to develop, operate and enhance the system;

- open access to and distribution of real-time, non-real time and archived data, with standardization of data formats to facilitate data use;

- derived products, decision tools and assessments, based on user requirements;

- ongoing evaluation of system performance, including oversight of the evolution of the system to ensure continuity, accuracy and efficiency;

- comprehensive coverage of U.S. coastal waters and the global ocean through national and international partnerships;

- evolution and improvement of the system as new knowledge and technologies become available.

IOOS Development

The need to more effectively integrate and enhance existing observing systems to protect and monitor ocean resources has been recognized and is being addressed at the U.S. national level by the development of the IOOS. IOOS is being designed to be robust, rigorous, reliable, responsive, and effective, and it will provide data and products in support of other IWGEO themes. Appendix I provides a list of the seven societal goals of IOOS, which are very similar to IWGEO themes. IOOS will consist of a national "backbone" of existing federal systems providing observations of key parameters at global and coastal scales (Appendix II, Table 1, Table 2, Table 3), a data management and communications process managed by federal agencies (Data Management and Communications System (DMAC) plan, see www.ocean.us), and a network of regional associations (RAs) whose purpose is to coordinate the many sub-regional observation programs into regional coastal ocean observing systems (RCOOSs). The RAs will include stakeholders from the broad ocean community, including state, local, and tribal governments; academia; private sector companies; and non-governmental organizations. They will serve the entire coast of the U.S., including the Great Lakes. The RCOOSs may comprise some or all of the portions of the national "backbone" located in the region, augmented by all other sustained observing systems in the region, such as water quality data collected by sanitary districts and networks operated by academic institutions that support local and regional user requirements. Detailed IOOS implementation and DMAC plans are found at www.ocean.us.

The initial IOOS will be only the existing federal system comprising the "national backbone" that provides sustained and reliable measurements of core parameters (Appendix II Tables 1, 2 and 3) at both global and coastal scales. These components are considered "operational" or "pre-operational". Other initial elements are research systems and other projects to demonstrate integration, improvements or new technologies and methods ("pilot projects), and the Data Management and Communications system. Appendix III lists the core IOOS parameters in priority order based on applicability to the seven IOOS themes. Appendix IV highlights candidate data management and communication standards and protocols proposed for IOOS.

For the global ocean, the national backbone systems will provide one or more of the following measurements in a sustainable, routine and standardized fashion:

- sea surface wind, wave and current fields;
- sea level;
- surface and interior fields of temperature and salinity;
- heat flux across the air-sea interface; and
- sea ice distribution and extent.

For coastal areas, the initial IOOS backbone will also supply the following parameters, in addition to those listed above for the global ocean:

- surface and interior fields of chlorophyll-a and macrozooplankton abundance;

- extent and condition of benthic habitats;

- distributions of spawning stocks of harvestable fish species, including protected species stock identification and structure, abundance and seasonal distribution, habitat requirements and prey species status; and

- land-sea freshwater flows and associated transports of sediments, nutrients and contaminants.

The optimal composition of the IOOS backbone, e.g., the systems that will be "integrated" at appropriate time and space scales to provide required products and information to users, will need to be determined, and will be based on collated and prioritized user requirements. Instrumentation from state and local governments, private sector or academic systems that is sustained and standardized (see a comprehensive listing in U.S. Ocean Commission, 2004) is also expected to be part of IOOS. These observational systems should be designed to allow for expansion as new operational instrumentation becomes available, as well as for the deployment of research instrumentation. Considerable detail about the stage of readiness for deployed observational systems is found in OCEAN.US (2002). Both backbone and RCOOS needs will be surveyed annually and a prioritized list of needs provided by the National Federation of Regional Associations (NFRA) as information to the funding agencies.

Based on the guiding principle of agreed upon standards, protocols and data formats (Appendix IV), the data management and communication system also includes easily accessible databases of required measurements, with formats that allow for integration at the user desktop, allow for intercomparisons and modeling hindcasts and forecasts, allow for assessments and simulations, and allow for development of products that illustrate current conditions, temporal variability and long term trends/future conditions. The system should provide data and information products at the user desktop, cell phone or bridge of the ship, for all range of user skills and expertise. Additionally, IOOS must support machine-to-machine interoperability with semantic meaning; i.e. incorporate some collection of methodologies that promote the scripted exchange of data between computers, with all computers involved in the transaction capable of determining both the syntax and the semantics of the exchanged data without human intervention.

IOOS is not the only U.S. contribution to GEOSS, though. There are important components of the U.S. contribution not included in IOOS. They include other measurement systems providing data to the ocean community, the many research efforts such as ORION that are producing data of value to a GEOSS, and the considerable satellite data collected by NASA satellites. The IOOS concept provides the framework to integrate disparate, existing observing systems under a common data management and communication system."

3. Existing Capabilities and Commonalities

There are many existing capabilities for monitoring ocean resources within federal agencies, state and local government, private companies, academic institutions, tribes and others. Some have been in place for decades or years, while others are implemented only for short term projects or studies. These systems were designed to support national mandates, living marine resource conservation, local management issues, specific research projects and other clients with varying purposes and user needs. They can be considered global, national, regional or local in nature, are in various states of readiness, and have various levels of support. Monitoring systems are based on surface (land and water), underwater and airborne or satellite platforms, and include *in situ* and remotely sensed measurements, and manual or autonomous operations.

Specific sensor types and networks include:

- Remote sensing instruments on aircraft, satellite and land-based platforms, such as: passive electro-optical imaging sensors (multispectral and hyperspectral) and active electro-optical (lidar); passive microwave (radiometers and sounders) and active microwave (altimeters, scatterometers, and Synthetic Aperature Radar), and high frequency radar; and

- Ship-based measurements, such as: net sampling; manual and pumped measurements of physical, chemical, optical and biological properties; and acoustic measurements of bathymetry and currents

- Coastal, open ocean, or land-based *in situ* systems that allow for unattended (autonomous or semi-autonomous) operation, such as: wind, wave and temperature sensors on moored buoys; drifters; shore based platforms such as tide gauges; water quality sensors; and autonomous underwater vehicles (AUVs).

- In water measurements that require attended operation, such as: manual sampling of underwater species; remotely operated vehicles (ROVs); underwater video/photography; and underwater laboratories.

- Sentinel and research sites located at the shoreline; in bays, estuaries, rivers, offshore, and the deep ocean; and on the ocean floor

- Systematic regional fisheries and protected species surveys conducted by observers on ships and aircraft to establish seasonal indices of abundance and distribution, and, from these, key indicator species over time

- Long-term sampling programs that measure contaminants in the water column, sediments and marine organisms, such as NOAA's National Status and Trends Program.

Orbital sensors are available on satellite missions, such as NOAA's Polar-orbiting Operational Environmental Satellites and Geostationary Operational Environmental Satellites; DOD's Defense Meteorological Satellite Program, NASA's Landsat, SeaWiFS, Terra, Aqua, TRMM, TOPEX/Poseidon and Jason-1 satellites; and various commercial ventures. Examples of global *in situ* systems include the Argo buoys, and the U.S. contribution of drifting buoys. Global systems that combine *in situ* and satellite assets include NOAA's contribution to Global Sea Level Observing System (GLOSS) and the U.S. Climate Observation Program. National *in situ* systems include NOAA's National Data Buoy Center (NDBC) networks of weather buoys and land-based measurement stations, National Water Level Observation Network (NWLON), Physical Operational Real- Time System (PORTS), and NOAA's Ecosystem Observation System (NEOS); EPA's National Coastal Assessment Program and National Estuary Program; and the USGS stream gauge network. Some of these systems may not be sustainable due to budget restraints. Examples of regional and local systems include the Rutgers University Coastal Ocean Observation Laboratory and the water quality monitoring networks of Southern California's sanitation districts. There are existing private sector networks that are also deployed.

Many of these deployed systems measure the same variables using the same, similar, or even different equipment and techniques. They may have different data collection frequencies, spatial scales, data quality control and processing procedures, and formats residing in databases or other media. Data may be available in real time, in a delayed mode, after days, months or years of processing and analysis, or not at all. An inventory of deployed systems is found in U.S. Ocean Commission (2004), in OCEAN.US (2002) and in other reports such as the Department of Commerce/NOAA, December 2003 draft report "NOAA's Integrated Environmental Observation and Data Management System". A listing of the systems considered as initial candidates for IOOS, along with measured parameters, is found in Appendix II.

NOAA's Ecosystem Observing System (NEOS) provides an example of an end-to-end coastal and oceanic ecological observing system for living marine resources (LMRs) that supports the NOAA's ecosystems management mandates. NEOS encompasses routine, operational and pre-operational observations (e.g., resource surveys), product development (e.g., assessments and forecasts), and research necessary to improve the technical capability of the Observation System to monitor and assess LMRs. Operational systems are the final part of a continuum ranging from research to pilot projects to pre-operational and then operational activities. An operational system is defined as one with routine and sustained provision of data and data products in forms and at rates specified by user groups, and is run by operational groups, with researchers functioning as advisories and users. A pre-operational system is defined as one that incorporates new techniques from pilot projects into operational systems that are likely to lead to value added product(s) and is run primarily by operational groups, but with involvement of researchers (Ocean U.S. (2003) U.S. Integrated Ocean Observing System part I).

NEOS also includes data management and production of routine technical reports (e.g., LMR stock assessments). This system will link to efforts of the EPA and USGS as outlined in subchapter 4.6. A companion to NEOS is the Ocean Biogeographical Information System (OBIS), considered to be a candidate for the main depository (portal) for the storage and disposition of biological data to be collected. See http://www.iobis.org for more details.

For the most part, currently deployed systems are not linked in terms of data discovery, availability or integration (ability to "overlay" datasets). Instrumentation for meteorological measurements, water temperature, salinity, and current speed and direction is available and widely deployed, but may not be available in some critical coastal or open ocean areas. Instruments used for water quality measurements are available, with others in varying degrees of development, but they are not uniformly deployed in threatened areas or baseline sites. Bio-optical instrumentation is available and used in an operational mode, with more instruments ready for transition from research to operations, but maintenance issues, such as bio-fouling, are still a significant problem and spatial coverage remains inadequate. Nearly operational nutrient sensors are being considered for various issues such as eutrophication in aquatic environments, occurrence of HABs, etc. Some of the new technology incorporates automated and above water measurements required for the calibration of satellite remote sensing data, but more sites are needed, especially in coastal regimes. Automated instrumentation for the detection of HABs is not available, though there are several promising technologies under development.

4. Major Gaps and Challenges

By the very nature of the complexity, interrelationships, time scales involved and extent of the phenomena involved in protecting and monitoring ocean resources, the implementation and evolution of a sustained and integrated, locally relevant and globally deployed ocean observing system will be a substantial challenge. This system can and should look to the example of the weather system for best practices and policies, standards and protocols and, if possible, for leveraging existing assets and lessons learned from international efforts such as EuroGOOS. All major components are required for full implementation and evolution of the system : data acquisition/data processing/data management (infrastructure); data and product communication; modeling of physical-ecosystem/watershed systems; research and development of new products, services and observational techniques; skilled personnel and administrative/financial systems. A concentrated effort will be required to more thoroughly understand marine ecosystems and the watershed environment, determine the optimum, best-value observing system to put in place, evolve and determine effectiveness on a regular basis, establish the key indicators of change, and determine how to implement and interpret assessments of interactions among ecosystems and the human population to make the most informed decisions about ocean resources.

Crucial to successful implementation will be the recognition that biases and paradigms exist that must be overcome.

Differentiating the effects of human activities from natural processes will require knowledge of the coherence of changes that are occurring locally on global scales and comparative analysis of such changes in the context of larger scale forcing. Therefore observations, analyses and comparative studies are needed well beyond the borders of the U.S., involving other countries in an integrated effort. Knowledge, data, infrastructure and expertise must be shared among nations for the most effective effort. Integration of observations with models, ecosystem characterization, simulation and decision support services for ecosystem-based management practice need more emphasis, and the place-based distributed nature of problems, solutions, observations and connections to managers must be taken into account. A significant, cooperative effort will be necessary to develop a monitoring system for living marine resources, building on existing programs within the federal agencies and of other partners within the IOOS.

Requirements/User Needs
Preliminary assessments of user needs have determined that enhancements to our observations of key variables in both time and space are needed for coastal and open ocean regions, prioritized according to the following criteria:

- the need for a consistent set of backbone ("core") measurements (Appendix II), over multiple scales, local to global, hours to decades, for the open ocean, coasts, Great Lakes to a) monitor and assess near shore processes, b) obtain spatially adequate and synoptic long term time series, c) provide transects and vertical profiles of key parameters, and d) provide high resolution vertical profiles;

- the need for time series with appropriate temporal and vertical resolution of key variables at "sentinel or research sites" to measure and record variability at key coastal and open ocean sites, thus establishing baseline conditions, documenting variability and providing the data needed to assess the performance of and improve models;

- recommendations for indicators (products) of ecosystem condition, by panels of experts both within the U.S. and internationally, and in reports such as the Heinz Center (2002) report on "The State of the Nation's Ecosystems".

A comprehensive detailed, ongoing assessment of the needed data that are available is necessary, which could be based on existing OCEAN.US and U.S. Commission on Ocean Policy documents. This assessment should be compared with user needs, which include representatives from state and local agencies (including Homeland Security agencies), private and academic sectors, along with the general public. As stated in the U.S. Commission on Ocean Policy report, user inputs are critical to defining specific information needs, operational requirements and outputs that would be most useful for various ocean resource needs. These needs will, in turn, drive observation system improvements. Special emphasis is needed for observations of biogeochemical parameters in addition to physical measurements in near-coastal ("green") and coastal ("brown") water environments, including wetlands.

Data management and communication
A robust data communications system and easily accessible databases that allow for rapid delivery of information and products is needed to overcome a considerable gap in data availability and access for ocean resource data. Key to data availability will be establishing standards and protocols for data discovery and transport that all operators follow, and a data communication system that supports the diversity and range of environmental and biological data transmissions from the ocean bottom and throughout the water column, in real time and in delayed mode. Data dissemination is also a substantial gap, as there is not a Global Telecommunications System equivalent for ocean data, and presently it is difficult and expensive to collect data from under water and in remote areas.

Research
An ecosystem approach to management that is adaptive and relies on data collected from ocean observing infrastructure would serve as the underlying concept for managing ocean resources. This lack of understanding presents a significant challenge for the ocean research community. The development and adoption of an ecosystem approach to coastal and ocean resource management will need to be incremental and collaborative, with clear definitions and technical guidelines building on existing capabilities. The controls on

physical, chemical, and geological oceanographic processes, as well as the biological and ecological complexity involved in an ecosystem approach to management, must be better constrained. An important contribution of the OOI/ORION Program (http://www.orionocean.org/) and the research component of IOOS will be to provide an improved understanding of the state of marine ecosystems, their natural sources of variability and their sensitivity to potential changes in the global climate system. This new knowledge will lead to a more effective application of ecosystem principles for managing resources. Also critical is an understanding of the socio-economic variables and trends related to ocean resource management. Some level of standards and protocols for research projects and pilot projects, perhaps as part of the transition from research to operations, is necessary to help manage existing and future efforts as IOOS develops.

An important product from this research will be improved data assimilation techniques and models that integrate physical, biological, geological and chemical data. Scientific research is essential for developing an effective and efficient operational observing system that will enable the monitoring and stewardship of coastal and ocean resources. To define an observatory network, it is essential that the spatial extent of the system and the temporal resolution of the data are optimized to meet user community needs. Often the design of an observing system is constrained for logistic and economic reasons and therefore the networks are rarely optimized to investigate the processes they are established to monitor. To overcome this, Observing System Simulation Experiments (OSSEs) utilize numerical models to assess the quality of potential sampling strategies, the results of which can then be used to optimize the observing system.

Dedicated basic and applied research is also needed to support improvements to existing or development of new measurement systems (remote sensing and *in situ*) to improve fundamental observing strategies for monitoring and managing resources, and to provide the basis for advances in forecasting and prediction. New technologies are required, principally in the realm of sensors that measure critical biological and chemical parameters in the ocean. Of particular concern are the high latitude oceans, since they are critical in the large scale heat balance and carbon cycle of the Earth system and in the global scale, thermohaline circulation of the ocean. They are particularly sensitive to climate change and the recipient of contaminants from lower latitudes, and yet their ecosystems have global importance. Observing the bathymetery, chemistry, physics and biology of the Antarctic and Arctic oceans will be a challenge and require new techniques and special instruments. Evolutionary changes in *in situ* measurements of key variables are expected from the public, private and academic sectors, with corresponding improvements in data communication, local data processing, and in assimilation of new data into predictive models. For example, more accurate and comprehensive remote sensing of key variables, particularly in coastal regions, is anticipated from new sensors on new satellite, aircraft, vessel, and autonomous vehicle platforms. Transitioning new knowledge into better measurements systems and improved deployment strategies for

IOOS requires effective partnerships between researchers, resource managers and those designing and implementing IOOS components.

A well-designed integrated ocean observing system requires that data quality be assured through well-developed calibration and validation programs. Calibration and validation must be a continual process through the deployment of any remote or *in situ* sensor. This ensures that variability observed in the data is caused by changes in physical and biogeochemical conditions in the environment, not by sensor drift. Similarly, to ensure the best possible data products, verification, maintenance, and improvements are required through the deployment history of the sensors. Calibration and validation programs are particularly important when multiple sensors are used for similar data products. Good examples are ocean color data products from SeaWiFS (SeaStar- OrbImage spacecraft) and MODIS (AQUA and TERRA- NASA spacecraft), where a calibration program was developed to ensure equivalence between these three satellite sensors. Similarly, when sensors failed or are deactivated and are substituted by new sensors, a good calibration record is needed to ensure continuity of equivalent, high-quality data. This is particularly important for sensor systems collecting climate data records. Future sensor systems must include in their design and execution calibration and validation programs. *Ad hoc* calibration/validation activities should be avoided and instead standards and protocols established. Calibration and validation of data is as important as data archiving and distribution. This effort requires a robust infrastructure of ships, aircraft, sensor systems, laboratory and personnel that must also be considered when designing a sustained system.

Observational and other gaps/challenges
Issues to overcome with respect to the observing components include: insufficient spatial distributions of observing sites; monitoring at inappropriate or inadequate time scales or patterns of variability; collection of measurements in different units and of varying quality; and delays in data collection, quality control and dissemination. Appendix V provides examples of a partial gap analysis for some observational parameters. OCEAN.US (2002) also contains considerable detail about gaps for all required IOOS parameters. Some key observational gaps are outlined below.

Remote sensing measurements:

- Improved procedures for calibrating and representing data in coastal waters

- Precise sea surface height and surface vector wind measurements

- Finer scale resolution sensors for sea surface temperature (SST), salinity, winds, ocean color (specific information can be obtained from NOAA

Observations Requirements document at www.nosc.noaa.gov for example)

- Continuity in ocean color, winds and sea surface height measurements
- Improved systems to determine quantity and quality of coastal habitats (intertidal, seagrasses, kelp beds, water column, sediments)
- Acquisition of ocean color imagery (multi- and hyperspectral) of coastal areas at sufficient frequency and optical resolution to identify and analyze changes in the spatial distribution and extent of coastal and nearshore habitats
- Integration of *in situ* measurements with remotely-sensed observations.

Ship-based measurements:

- Expanded ship-based measurements of temperature and salinity profiles (need to equip more ships of opportunity)
- Better determination of global fluxes of heat, fresh water and carbon (need to repeat a World Ocean Circulation Experiment [WOCE] – type experiment)
- Comprehensive and standardized fisheries and protected species surveys to measure relative abundance from fishery-independent data to improve the quality of living marine resources (LMR)stock assessments and the understanding of population dynamics, e.g. more days at sea
- Multi-beam sonar measurements to collect detailed bathymetry and habitat information, particularly in nearshore and shelf environments, but also in watersheds and out to the EEZ

In situ measurements:

- Long-term, continuous measurements of river flow volume at more sites.
- Additional sites for water level measurements
- More frequent sampling of key properties, such as sediment load, nutrient concentration and selected chemical contaminants, at more sites

- Better systems to determine quantity and quality of coastal habitats (intertidal, seagrasses, kelp beds, water column, sediments)

- Expanded coastal network of moored instruments at more locations that measure meteorological variables (including atmospheric deposition) and oceanographic properties (physical, chemical, biological)

- Additional deep ocean observatories and sentinel sites

- New remote sensing/AUV technologies/techniques to obtain fishery-dependent and fishery-independent data

- Innovative and cost effective techniques to eliminate the need for manual sampling, photography, etc.

- Standardization of methodologies for biological community sampling

- Improve methods for validation of benthic habitat map products

Other challenges include needs for the following, arranged by subject area:

Observing system development and management:

- Coordination of federal agencies that manage, assess, map, and chart resources, with the goal of creating standardized, easily accessible national maps that incorporate living and non-living marine resource data along with bathymetry, topography, and other natural features. Investigate expansion of existing and creation of new data clearinghouses for marine spatial data to more effectively share multi-agency data.

- Inclusion of pipelines, off shore platforms, vessels, and related research and monitoring programs in IOOS.

- Flexible data policy for classified data and other datasets involving commercial interests (e.g., fishing information, precise geophysical information of interest to the oil and gas industry, etc.)

Resource management support:

- Tools to transform measurements into products such as predictions of environmental change.

- A systematic, sustained, monitoring system for water quality on national or global geographic scales necessary to meet the needs for assessment of impacts of decreasing water quality on living marine resources, habitats, and human health and the economy.

Research:

- Assimilation of remotely sensed data into models.
- Continued improvement of coupled biological-physical models.
- Identification and establishment of additional sentinel and research sites.
- Closing gaps in knowledge of ecosystem effects upon LMR's, including the effects of environmental variability and climate change, functional habitat alteration, and long-term environmental degradation
- Closing gaps in knowledge of multispecies interactions so they can be incorporated, along with ecosystem considerations, into stock assessments and management advice
- Systematic research, monitoring, assessment, and technology development required to truly achieve meaningful sediment management. The impacts on natural sediment processes of dredging, infrastructure projects, farming, urban development, any many other necessary and beneficial human activities are not well understood.
- Collaborative projects among scientists and commercial and recreational fisherman to increase understanding of mutual needs and expertise.
- Research on the impacts of all types of vessel pollution.
- Expand multidisciplinary studies of the evolution, ecology, chemistry, and molecular biology of marine species, discover potential marine bioproducts, and develop practical compounds
- Additional research in other parts of the world.
- Identification of the critical research and data needs related to coral reef ecosystems, through the U.S. Coral Reef Task Force

- Additional research into ocean acoustics and the potential impacts of noise on marine mammals

- Expansion of marine aquaculture research, development, training, extension, and technology transfer programs

- Socioeconomic research to examine the human dimensions and economic values of the nation's oceans and coasts and encourage ocean research agencies to include socioeconomic research as part of their efforts.

Infrastructure –

- An analysis of ship and aircraft time, including small boats, required to support the initial and evolving system.

- An analysis of information technology and instrumentation required to support research, calibration/validation, transition to operations, modeling and OSSE's required for the initial and evolving system.

- An analysis of types and skills of personnel required for the initial and evolving system.

5. Future Earth Observation Systems that May Fill Gaps

Evolutionary changes in *in situ* measurements of key variables are expected, with corresponding changes in data communication and local initial data processing (QC/QA checks for example). More accurate and comprehensive remote sensing of key variables in coastal regions is expected in the next generation of U.S. satellites (GOES-R, NPOESS), aircraft, ships and AUVs. Additional details will be identified in the process of developing gap analyses and future requirements. An example of current and future EO systems for ocean resources is found in Appendix VIII. Future needs are also documented in OCEAN.US, 2002.

"Foreign systems" requiring partnerships with other governments and agencies that are expected to be useful for ocean resources and are reasonable certain are:

- Aquarius from Argentina and the U.S. (CONAE/NASA). This is an ESSP mission whose purpose is to measure ocean salinity with an L-band radiometer. It is currently scheduled for flight in 2008.

- GPM-Core (Global Precipitation Mission) from Japan and the U.S. (JAXA/NASA) will carry a radar for measuring precipitation, and is presently scheduled for launch in 2008.

- Metop is a series of three satellites from ESA/EUMETSAT. With NPOESS, they will comprise a joint U.S./European environmental monitoring constellation of four satellites, by about 2009. Some of the instruments on Metop are U.S.-provided. The three satellites are planned for launch in 2005, 2009, and 2013.

Many other international systems with ocean resource applicability are planned or envisioned for the coming decade. Some of these are to be realized in partnership with the U.S., while many others are purely "foreign" systems. Most of the purely foreign systems come from countries that do not readily share such data with the U.S. today; this issue will need to be addressed through the GEO process. The purely foreign future systems that appear to be reasonably certain are:

- IRS-P7/Oceansat-2 from India, which includes ocean color imagery, scatterometry, and passive microwave imagery. It is currently scheduled for launch in 2005.

- RISAT from India, which is a C-band SAR mission, scheduled for launch no earlier than 2006.

- Megha-Tropiques from India and France, whose payload includes the MADRAS microwave imager, scheduled for launch no earlier than 2006.

- HY-2 and HY-3 from China (PRC), whose payloads have variously been defined as measuring ocean color and temperature, or ocean wind, wave height and temperature. The earliest possible launch dates appear to be 2004 and 2006, respectively.

- The FY-3 series of polar-orbiting meteorological satellites from China, due to begin replacing the current FY-1 series no earlier than 2005. The payload includes visible/infrared and microwave imagers that appear to have oceanographic utility.

- RADARSAT-2 and 3 from Canada, both flying C-band SAR systems that are useful for studies of sea ice. RADARSAT-2 is scheduled for launch in or after 2005, while the payload modifications and launch date for RADARSAT-3 remain poorly defined.

- SMOS from France and Spain, carrying an L-band sparse-aperture thinned array radiometer dubbed MIRAS that will measure ocean salinity.

- The Okean series from Russia and Ukraine (the versions from Ukraine are also dubbed Sich). The satellites in this series have been delayed due to funding problems, their future is uncertain, and satellite designations can be confusing. It appears that Okean-01-N9/Sich-1M will be launched in 2004, carrying infrared and microwave imagers.

Much work remains to be done to ensure the ready availability of data from the majority of these systems.

6. Interagency and International Partnerships

Federal agencies are involved with a number of national and international partnerships involving ocean resource data. U.S. federal agencies and the U.S. ocean research community have played lead roles in development of the global ocean observing system (GOOS), global and basin scale satellite systems and of international research programs of global scope, including WOCE, JGOFS, TOGA, CLIVAR, SOLAS, CEOS, and IMBER. These efforts do much to lay the foundations for the partnering required to achieve the required coverage of the global ocean and of coastal waters contiguous to those of the U.S. The GEO process must continue to support the efforts of the U.S. ocean research community, and strengthen and formalize critical international partnerships, so that global coverage and open access to all nation's ocean data are assured. Appendix VI contains a table showing a partial list of existing partnerships. A partial list of national and international partnerships is found in Appendix VI.

In addition, there has been considerable national and international activity and cooperation over the past 10 years toward the development of an IOOS. There has been an interagency effort to create a national and international network of observations, data management and analyses that systematically acquire and disseminate data and information on past, present and future states of the oceans, particularly with the Exclusive Economic Zone (EEZ). IOOS is the U.S. component of a larger Global Ocean Observing system (GOOS) that is being developed under the auspices of IOC/UNESCO.

IOOS is being developed as a national partnership among federal and state agencies and regional associations that represent both users and operators of the system. The National Ocean Research Leadership Council (NORLC) develops policies and procedures for IOOS design and implementation, and receives advice from the Ocean Research Advisory Panel. NORLC approved the establishment of an office (OCEAN.US), having the charter to oversee the development of a national capability for integrating and sustaining ocean observations and predictions. NORLC's Executive Committee (EXCOM) oversees all the activities of the OCEAN.US office, and is composed of representatives from 10 federal agencies (see http://www.nopp.org). Participating government agencies and regional associations implement those elements of the IOOS that are consistent with their missions, goals, and priorities. International coordination and cooperation is maintained through the U.S. Global Ocean Observing System steering committee, which is represented in the GOOS effort.

Joint partnerships within relevant IWGEO agencies are required for:

- the development of a strategy for assessment, monitoring, research, and technology development to enhance sediment management;

- a national water quality monitoring network that coordinates existing and planned monitoring efforts, including monitoring of atmospheric deposition, and that provides timely and useful information products that are easily accessible to the public and linked to output from the IOOS

- a plan for transferring new technologies to an operational mode in the IOOS;

- a joint ocean and coastal information management and communications program to generate information products relevant to national, regional, state, and local needs on an operational basis;

- periodic review and declassification of appropriate oceanographic data for access by the ocean community.

- making use of industry platforms (ships, drilling and production rigs) for sampling the surface and interior of the ocean and providing to industry the information about currents, waves to support exploration into deeper waters and more challenging environments in search of petroleum and gas hydrates resources

7. U.S. Capacity Building Needs

Current capabilities and capacities are insufficient to satisfy national and international ocean resource observing requirements. At a minimum, capacity building must involve developing and maintaining technical expertise and infrastructure (people, systems, data management, platforms, ships, aircraft) of federal and state observations networks, research efforts and data management required to participate in an integrated ocean observing system.

Key areas for capacity building are data management and communication, combining remotely sensed data with *in situ* data, a system to transition research into operations, and providing enhanced sensor packages that are automated and require less maintenance than currently for biogeochemical measurements, and remotely sensed technologies including remotely-operated vehicles, small automated free flyers, and/or modeling to increase the observational network capacity.

Other specific needs include:

- Additional habitat conservation and restoration assessments, monitoring, research, and education;
- Additional sustainable development and conservation of renewable ocean and coastal resources through grants to all coastal states;
- expanded national ocean exploration program
- Developing a robust and cost effective data communication system that work well underwater and handles all forms of ocean resource data

8. Conclusions

A basic objective of ocean observing systems for the coming decade is to help generate the optimal value (i.e. maximize net benefits) to society from our nation's oceans and coastal resources in a sustainable, economically viable and environmentally healthy manner. Priorities include ensuring food security through sustainable management of natural and aquaculture fisheries, improving water quality and management of sediments and shorelines, promoting safe and free transit and navigation, and minimizing and/or mitigating the occurrence of coastal and ocean-related hazards. Taken together, these priorities will promote healthy coastal and ocean environments that ensure sustained ecosystem health, including that of human populations. The system also support the other IWGEO theme areas.

The highest priority actions needed to protect and monitor ocean resources include the following:

1. Maintain infrastructure to operate existing global and coastal elements of the national ocean observing backbone (Appendix II) and promote integration of these existing systems;
2. Enhance the global and national backbone by a) continuing to implement Argo, tide gauge stations and ship-based networks and increase the coverage of coastal and open ocean time series stations (fixed and drifting buoys, CMAN); b) adding biological and chemical sensors (salinity, bio-optics, nutrients, dissolved oxygen, pCO2) to coastal and near coastal sites; c) adding sea level gauges and river water quality and level instrumentation at more coastal sites; and d) more frequently sampling sediment load, nutrient concentration and selected chemical contaminants (USGS, NOAA, Navy, EPA and USACE systems);
3. Establish standards and protocols for measurements, data exchange and management to allow for rapid access to diverse data from disparate sources. Implement data standards and protocols for metadata management and data discovery, data transport, uniform on-line browse and archive for the core national backbone ocean parameters collected from existing observing networks.
4. Institute a yearly planning process to involve all components of an integrated ocean observing system, to determine priorities and implementation plans.

Priorities for general and other specific investments for IOOS have been documented in NOAA et al (1999), NOPP (1999), OCEAN.US documents (see www.ocean.us), the U.S. Commission on Ocean Policy (2004), and are highlighted below. Additional details about timelines for implementation, and preliminary estimates of amount and cost of enhancements are found in OCEAN.US, 2002. All recommendations should be coordinated within the IOOS community and among the IWGEO agencies in order to prioritize the type, location and frequency of measurements needed to appropriately monitor local, regional and national conditions, using an agreed upon and cost effective approach.

An ideal observing system development schedule follows, arranged by timeframe (which could be modified as more information becomes available):

Immediate implementation (e.g., begin now, complete in 1-2 years) –

1) Reaffirm the initial IOOS core set of variables to be collected by the national backbone with user groups. The core variables should include appropriate biological, chemical, geological, and physical variables. This effort will require an initial inventory of parameters currently collected by national backbone components and regional observing systems.

2) Develop and maintain a comprehensive inventory of federal and regional observing system capabilities (platforms and sensors).

3) Develop a process to continuously assess the effectiveness and relevance of deployed observing systems for monitoring ocean resources.

4) Implement data standards and protocols for metadata management and data discovery, data transport, uniform on-line browse and archive for all core/backbone ocean parameters.

5) Establish national and regional research and modeling priorities to address key ocean resource issues.

6) With key user input, identify information products that address key ocean resource issues.

7) Maintain existing capacity for high resolution bathymetric surveys of the continental shelf to support marine transportation, national security, recreational and commercial fishing and energy industry interests.

Short term implementation (e.g begin planning or implementation and complete in 3-5 years)

1) Integrate global observations with coastal/regional observations to improve the detection and prediction of the effects of global scale weather and climate patterns on ecosystems.

2) Facilitate capacity building within regions (which include public, private and academic sectors) by developing and sustaining regional associations (RA) and regional coastal ocean observing systems (RCOOS).

3) Expand and enhance moored instruments in inland seas (estuaries, bays, sounds Great Lakes) and in the EEZ for synoptic measurements of meteorological and oceanographic properties.

4) Establish a national surface current mapping system in the coastal areas and out to 200 km.

5) Increase the frequency of high resolution bathymetric surveys of the continental shelf to support marine transportation, national security, recreational and commercial fishing and energy industry interests.

6) Increase the frequency of combined topographic shoreline and nearshore bathymetric surveys.

7) Continue to implement global ocean time series observatories and the Global Ocean Data Assimilation Experiment

Longer-term implementation (e.g. begin planning or implementation now and complete in 5-10 years) –

1) Develop operational *in situ* and/or remotely sensed systems to monitor and predict changes in selected species of living resources and quality and quantity of coastal habitats.

2) Develop nowcast/forecast systems for currents, water levels and winds (PORTS) for all major U.S. ports and coastal waters.

3) Ensure continuity of calibrated, consistent satellite ocean color data sets.

4) Develop statistical modeling capabilities that integrate biological (e.g., primary production, fishery, protected resource) information and environmental information (e.g., physical, chemical, geological) to understand ecosystem forcing mechanisms that affect LMR dynamics and status, to develop forecasts and to evaluate coastal and ocean resource management alternatives and performance.

5) Establish a network of sentinel (reference) stations to provide baseline data to assess the significance of local variability and develop early warning indicators.

6) Develop indices of ecosystem health from observing system measurements.

7) Better integrate existing observing networks by minimizing redundancy in data collection and optimizing data and information exchange.

8) Transition remote sensing capabilities of ocean topography, ocean vector winds, ocean color, SST and sea ice from research to operations, sustain this capability and make more accessible.

9) Develop *in situ* and/or remotely sensed systems to monitor and predict changes in selected species of living resources and quality and quantity of coastal habitats (intertidal, seagrasses, kelp beds, water column, sediments)

10) Establish systematic LMR surveys and assessments to develop information on LMR status trends over time

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Appendix I: The seven societal goals and related sub goals of the IOOS

SOCIETAL GOALS	SUBGOALS
Improve weather forecasts & predictions of climate change	(1) Obtain improved estimates of surface fields & surface fluxes; (2) improve predictions on seasonal & longer time scales; (3) Detect & assess the impact of climate change on the coastal zone; (4) Establish & maintain infrastructure & techniques to ensure efficient data acquisition & effective use of information.
Improve safety & efficiency of marine operations	(1) Maintain navigable waterways; (2) Improve search, rescue, & emergency response capabilities; (3) Ensure safe and efficient marine operations.
Provide more timely predictions of natural hazards & their impacts	(1) Improve data acquisition capabilities on time-space scales required to assess the physical & ecological contributions to hazard-risk; (2) Improve predictions; (3) Provide timely dissemination & convenient online access to real-time hazards, observations, & warnings; (4) Complete metadata & retrospective information on all aspects of disaster reduction; (5) Improve observational capabilities by making them functional over wider areas, for longer periods, & greater reliability.
Improve national security	(1) Improve the effectiveness of maritime homeland security & war-fighting effectiveness abroad; (2) Improve safety & efficiency of operations at sea; (3) Establish the capability to detect & predict the dispersion of airborne & water-borne contaminants in ports, harbors, & the littoral zone at home & abroad; (4) Support environmental stewardship; (5) Improved at-sea system performance through more accurate characterization & prediction of the marine boundary layer.
Reduce public health risks	(1) Establish nationally standardized measures of the risk of illness or injury from exposure to pathogens, toxins, hazards, & dangerous marine animals (water contact); (2) Establish nationally standardized measures of the risk of illness from consuming seafood.
Sustain, protect & restore healthy marine & estuarine ecosystems	(1) Determine regional ecological climatologies for sea surface temperature, salinity, dissolved nutrients, chlorophyll-a, & harmful algal species; (2) Provide more timely detection & improved predictions of changes in the spatial distribution & condition of biological structured habitats (coral reefs, sea grasses, mangroves, & tidal marshes), in species diversity, of indicators of coastal

Sustain, protect & restore marine resources	eutrophication, of harmful algae (presence, growth, movement & toxicity), of non-native species (presence & probability of invasion), of diseases in & mass mortalities of marine animals (fish, mammals, birds), of the effects of habitat modification on species diversity; (3) Monitor anthropogenic contaminants & their effects on organisms & ecosystems. (1) Provide improved & more timely prediction of annual fluctuations in spawning stock size, distribution, recruitment, & sustainable yields for exploitable fish stocks; (2) More timely detection of changes in the spatial extent & condition of essential fish habitat; (3) Improved predictions of the effects of fishing on habitats & biodiversity; (4) Establish & monitor the effectiveness of Marine Protected Areas.

Appendix II: National Backbone Elements for the Global and Coastal U.S. Components of the initial Integrated Ocean Observing System (IOOS)

Table 1. GLOBAL: Pre-operational and operational programs that constitute the global component of the initial IOOS listed by core variable and by the responsible federal agency.

VARIABLE	NOAA	NAVY
Temperature	Geostationary satellites (GOES) Polar-orbiting operational environmental satellite (POES) Voluntary observing ships Ships of opportunity Dedicated Ships Moored Buoys (Tropical Array)[a] Drifting Buoy Array Arctic flux & sea ice NWLON	Integrated buoy program Ocean Survey Ships
Salinity	Voluntary observing ships Ships of opportunity Dedicated Ships Drifting Buoy Array Arctic flux & sea ice	Integrated buoy program Ocean Survey Ships
Waves		Geosat Follow-on Ocean Survey Ships Integrated buoy program
Currents, Sea surface topography	Moored Buoys (Tropical array) [a]	Ocean Survey Ships
Winds	Dedicated Ships Drifting Buoy Array Arctic flux and sea ice Tide Gauge Network	WINDSAT Integrated buoy program Ocean Survey Ships
Sea Level	NWLON	Geosat Follow-on

[a] NOAA uses data from *in situ* measurements and remote sensing (e.g., sea surface temperature, roughness and height) to provide operational predictions of El Nino-Southern Oscillation (ENSO) events as well as sea surface wind, wave, and current field.

Table 2 COASTAL: Pre-operational and operational programs that constitute the national backbone of the coastal component of the initial IOOS* are listed by federal agency for each core variable.

Core Variable	**NOAA**	**Navy**	**USACE**	**USGS**	**EPA**
Sea surface winds	C-MAN[a], NWLON[b] NDBC[c], PORTS[d]	Integrated buoy program			
Stream flow				Stream gauging, NSIP, NASQAN	
Temperature	GOES, POES[e],NDBC, C-MAN, NWLON, PORTS, LMR-ES[f]	Integrated buoy program			
Salinity	LMR-ES, PORTS	Integrated buoy program			
Coastal Sea Level-Topography	NWLON	ADFC[g]		NSIP	
Waves	NDBC	Integrated buoy program	Coastal Field Data Collection Program		
Currents	NDBC, PORTS, National Current Observation Program				
Dissolved Inorganic Nutrients	LMR-ES Habitat assessment				National Coastal Assessment (NCA), Program;National Estuary Program (NEP)
Chlorophyll	LMR-ES				NCA,NEP
Habitat & Bathymetry	Hydrographic Survey Coral reef mapping Coral reef monitoring Coastal mapping Topographic change mapping Benthic habitat mapping Habitat assessment Coastal change assessment mapping		Hydrographic Surveying	Coral reef mapping & monitoring Coastal change mapping Benthic habitat mapping	NCA,NEP

Core Variable	NOAA	Navy	USACE	USGS	EPA
Plankton Abundance	LMR-ES				NCA,NEP
Abundance & distribution of LMRs & protected species	LMR-ES National observer				NCA, NEP (fish species)
Population[h] Statistics	LMR-ES National observer				NCA, NEP
Fish Catch	National observer Recreational fisheries Commercial statistics				

[a] Coastal-Marine Automated Network
[b] National Water Level Operational Network
[c] National Data Buoy Center (moored meteorological sensors)
[d] Physical Oceanographic Real-Time System
[e] Polar orbiting Operational Environmental Satellite (includes AVHRR)
[f] Living Marine Resources-Ecosystems Survey
[g] Altimeter Data Fusion Center
[h] Population statistics = sex, weight, length, and stomach contents
* EPA programs were added after the initial IOOS list was published

Table 3. NON-OCEANIC VARIABLES: required to quantify important drivers of change in ocean and coastal systems. Atmospheric measurements over the ocean and measurements of surface water transports from land are considered part of the IOOS.

Atmospheric	Terrestrial	Human Use
Wind vectors	River & stream flows	Sea food contamination
Air temperature	Ground water discharge	Sea food pathogens
Atmospheric pressure	Mass transport of sediments	Fish catch & effort
Precipitation (dry, wet)	Mass transport of nutrients	Sea food consumption
Humidity	Mass transport of contaminants	Beach usage
Aerosol concentration		Generation of underwater sound
Ambient noise		
Atmospheric visibility		

Cloud cover		

APPENDIX III. Cross-walk of Core Variables Required for Ocean Resources and IOOS Themes

Provisional IOOS core variables, listed in priority order, and the corresponding societal goals for which each variable is most relevant. These are nearly identical to similar suites of core variables identified in the GOOS/GCOS action plan, the EuroGOOS survey, the Coastal Ocean Observations Panel of the IOC, and in the 1999 NORLC report to Congress. Physical variables are ranked high because they are required to achieve all seven societal goals. Variables in bold were also identified by the Coastal Ocean Observations Panel as core variables using a similar procedure. This list of variables is augmented by data on atmospheric, land-based and anthropogenic forcings in Appendix II.

Core Variables	**Weather & Climate**	**Marine Operations**	**Natural Hazards**	**National Security**	**Public Health**	**Healthy Ecosystems**	**Sustained Resources**
Salinity	X	X	X		X	X	X
Temperature	X	X			X	X	X
Bathymetry	X	X	X	X	X	X	X
Sea Level	X	X	X	X		X	X
Surface waves	X	X	X	X	X	X	X
Surface currents	X	X	X	X	X	X	X
Ice distribution	X	X	X	X			
Contaminants				X	X	X	X
Dissolved Nutrients					X	X	X
Fish species						X	X
Fish abundance						X	X
Zooplankton species					X	X	X
Optical properties				X		X	X
Heat flux	X					X	X

Ocean color	X	X				X	X
Bottom character	X	X				X	X
Pathogens				X	X	X	X
Dissolved O_2						X	X
Phytoplankton species	X	X		X	X	X	X
Zooplankton abundance						X	X

APPENDIX IV. Candidate standards and protocol-related activities identified in the DMAC Plan.

DMAC Component	Existing Element	Sponsoring Agency	URL
Metadata	FGDC[a] and GOS[b]	USGS[a]	http://www.fgdc.gov/metadata/metadata.html http://www.geo-one-stop.gov/index.html
Data Discovery	GCMD[c] NCDDC[d] CSC[e]	NASA NOAA	http://gcmd.gsfc.nasa.gov/ http://www.ncddc.noaa.gov http://www.csc.noaa.gov
Data Transport	OPeNDAP[f]	Navy, NASA, NOAA, NSF	http://www.unidata.ucar.edu/packages/dods/
On-Line Browse	LAS[g]	NOAA	http://www.feret.noaa.gov/LAS/
Data Archive	NSF[h]	NOAA, DOE	www.nsf.gov/pubsys/ods/getpub.cfm?ods_key=nsf94126
Data Communications	GTS[i]	WMO and NOAA	www.wmo.ch/web/www/TEM/gts.html

[a] Federal Geographic Data Committee: The FGDC steering committee is composed of representatives from nineteen Cabinet level and independent federal agencies including: DOC, DOI, DOD, NSF, NASA, EPA, DOT, DOE, DoA. Funding for FGDC is appropriated through DOI/USGS.
[b] The Geospatial One-Stop (GOS) is sponsored by the Federal Office of Management and Budget to streamline access to geospatial information for users. Both GOS and FGDC support the National Spatial Data Infrastructure (NSDI) and the E-Government initiative. NSDI focuses on the technologies, policies, and people necessary to promote sharing of geospatial data. E-Government emphasizes the use of Internet-based technology to simplify interactions with the Government.
[c] NASA Global Change Master Directory
[d] NOAA National Coastal Data Development Center
[e] NOAA Coastal Services Center
[f] Open Source Project for a Network Data Access Protocol
[g] Live Access Server
[h] The NSF policy statement is under revision
[i] The Global Telecommunications System is the worldwide terrestrial satellite telecommunications network that serves data to World Meteorological Organization member nations for forecast operations under the international World Weather Watch.

Appendix V. – Partial Gap Analysis

Variable	Data Sources	Gaps
SST	Voluntary Observing Ship (VOS), Drifters, Orbital Sensors	Low quality data sets (VOS); Clouds/aerosols are a problem with satellite data and the data needs *in situ* help
SSS	VOS, Drifters, Buoys	Low quality data; need more *in situ* data; need orbital capability
Subsurface SST, SSS	VOS, XBTs, Tropical Atmosphere-Ocean buoy array (TAO)	Limited Salinity data for Global Ocean
Surface Currents; Tide Data	NDBC network, Coastal-Marine Automated Network (C-MAN) shore stations, VOS, TAO, PORTS, Orbital Sensors	Poor data quality in currents; poor spatial coverage; Continuity in Sea wind fields and ocean surface topography not vouchsafed
Sediment Size and Chemistry; Benthos Characteristics	Ship monitor data, *in situ* estuarine sites, Mussel Watch site network, Coastal Intensive Sites Network (CISNet) pilot studies, Satellite image data	More sites needed in crucial areas – more geographic coverage; Chlorophyll and sediment estimates from satellite sensor data in coastal waters need refinement; need better algorithms to extract bottom type in clearer coastal water areas
Global Sea Level	GLOSS, NOAA NWLON	Network needs updating; more complete geographic coverage needed
Event Induced Sea Level Shifts (e.g. Hurricanes, Tsunamis)	Satellite imagery, Hurricane Hunter flights; Pacific Rim array of tide gauges	Good for detecting hurricanes or tsunamis but forecasting needs refinement; for tsunamis need more detectors in source areas
CO_2 Flux	VOS; research cruises	Relative dearth of global data
Sea Ice	Drifters, Satellite, Airborne Lidar	Cloudiness in polar regions a problem for passive sensors; adequate active sensors needed

Appendix VI. Partial Listing of National and International Partnerships

Partnership	Participating Agencies
Climate Change Science Program (CCSP)	National Oceanic and Atmospheric Administration (NOAA) National Science Foundation (NSF) National Aeronautics and Space Administration (NASA) Department of Energy (DOE) Department of the Interior (DOI) U.S. Department of Agriculture (USDA) National Institutes of Health (NIH)
Coastal Ocean Observations Panel (COOP)	NOAA, NSF, NASA, DOE, EPA U.S. Navy (USN) U.S. Coast Guard (USCG) U.S. Geological Survey (USGS) Defense Advanced Research Projects Agency (DARPA) Minerals Management Service (MMS) Office of Science and Technology Policy (OSTP) Office of Management and Budget (OMB) Department of State (DOS) U.S. Army Corps of Engineers (USACE)
Integrated and Sustained Ocean Observing System (IOOS)	USN, NOAA, NSF, NASA, DOE, EPA, USCG, USGS, DARPA, MMS, OSTP, OMB, DOS, USACE
Global Ocean Observing System (GOOS)	USN, NOAA, NSF, NASA, DOE, EPA, USCG, USGS, DARPA, MMS, OSTP, OMB, DOS, USACE
Global Water and Energy Cycle (GWEC)	NOAA, NSF, NASA
Global Ocean Data Assimilation Experiment (GODAE)	NOAA, NSF, DOE, NASA, USN
Climate Variability and Predictability (CLIVAR)	NOAA, DOE, NSF, NASA
Joint Global Ocean Flux Study (JGOFS)	NOAA, DOE, NSF, NASA, USN
World Ocean Circulation Experiment (WOCE)	NOAA, NASA
World Meteorological Organization (WMO)	NOAA, NASA
World Climate Research Program (WCRP)	USN, NOAA, NSF, NASA, DOE, EPA, USCG, USGS, OSTP

Partnership	Participating Agencies
U.S. Global Change Research (USGCR)	DOE, NIH, DOS, DOI, EPA, NASA, NSF, USDA Dept. of Defense (DOD) Agency for International Development, Smithsonian

APPENDIX VII : Examples for Capacity Building

Variable	Gaps	Capacity Building
SST	Low quality datasets (VOS); Clouds/aerosols are a problem with satellite data and the data needs *in situ* help	Need more SSS drifters deployed; further development of networked buoy systems; possible use of Brillouin Lidar
SSS	Low quality data; need more *in situ* data; need orbital capability	Deploy more SSS sensors – both *in situ* and orbital (e.g. SMOS, Aquarius)
Subsurface SST, SSS	Limited Salinity data for Global Ocean	Develop profiling buoy networks and drifters; possible use of Brillouin Lidar
Surface Currents; Tide Data	Poor data quality; poor spatial coverage; Increased coastal coverage needed; Continuity in Sea wind fields and ocean surface topography not vouchsafed; need high resolution tide gauges with GPS receivers on them	Increased coastal coverage needed; need high resolution tide gauges with GPS receivers on them; orbital SAR data
Sediment Size and Chemistry; Benthos Characteristics	More sites needed in crucial areas – more geographic coverage; Chlorophyll and sediment estimates from satellite sensor data in coastal waters need refinement; need better algorithms to extract bottom type in clearer coastal water areas	Data synergy using hydrographic lidars and hyperspectral sensors; multi-wavelength lidars; improved hyperspectral algorithms
Global Sea Level	Network needs updating; more complete geographic coverage needed	Increased coastal coverage is needed; data needs to integrated into high resolution global coastal network
Event Induced Sea Level Shifts (e.g. Hurricanes, Tsunamis)	Good for detecting hurricanes or tsunamis but forecasting needs refinement; for tsunamis need more detectors in source areas	Need high density satellite and airborne remotely sensed winds; UAV use for outer wind structure; wind algorithm development

Variable	Gaps	Capacity Building
CO_2, heat and freshwater flux	Increased coverage is needed	Increased coverage is needed to resolve poor spatial resolution
Sea Ice	Cloudiness in polar regions a problem for passive sensors; active sensor lack needed spatial resolution	Orbital/Suborbital active sensors needed (with improved spatial resolution)

APPENDIX VIII. Examples of Future Earth Observing Systems

Parameter/ Question	Implementation Details	*In Situ* Measurements	Technical Readiness	Operational Potential thru 2014	Partnership Potential
Global Precipitation (V1)	Requires 6-8 satellite constellation for time resolution	Rain gauges, buoys, weather radar (NOAA, WWW)	Demonstrated by TRMM and passive µwave imagers	TBD; only passive µwave currently planned	Excellent – several needed
Ocean Surface Topography (V2)	Prefer orbits that avoid tidal aliasing	Tide gauges (Global Geodedic Network)	Demonstrated. Development needed for denser coverage	Under study by NPOESS	Continuation of current partnerships likely
Ocean Surface Winds (V2)	Active / passive µwave technique required	ships, buoys (NOAA, WWW)	Demonstrated by NSCAT and Seawinds	NPOESS requirement may be fulfilled	Seawinds and follow-on cooperation with Japan
Sea Surface Temperature (V2)	Both IR and microwave needed for all-weather observation	ships, buoys (NOAA, WWW)	Excellent	NPOESS requirement	EUMETSAT coordination
Sea Ice Extent (V2)	Microwave sensors needed for all-weather measurements	Ships, airborne reconnaissance (Navy, USCG, NOAA)	Excellent	NPOESS requirement	NASDA cooperation
Marine Primary Productivity (V3)	Very precise inter-satellite calibration is essential	NASA-SIMBIOS time series studies	Demonstrated	Partially provided by NPOESS	Cooperation with Japan, Europe possible
Ice Surface Topography (V5)	Excellent vertical resolution and accuracy needed for mass balance studies	GPS (NASA, NSF)	ICEsat lidar altimetry demonstration	Not currently an operational requirement	Coordination with European radar altimetry satellite
Gravity Field (V6)	Requires high precision	Geodetic networks	GRACE demo. pending	DOD interest in precise geoid	Possible
Total Solar Irradiance (F1)	High absolute accuracy, overlap of successive records required	global surface networks, buoys (BSRN, WRDC, SURFRAD, NOAA)	Excellent	NPOESS requirement	Possible
Solar UV Irradiance (F1)	Spectral resolution & good radiometric accuracy req'd	USGCRP UV network, NDSC (multiagency)	Excellent	NPOESS measurement planned	Strong history of cooperation
Earth radiation Budget (R1)	Broadband radiometry	Buoys (NOAA)	Excellent	Planned on NPOESS	Possible
Snow Cover & Accumulation (R1)	Need to assess snow depth or water equivalent quantitatively	Snow transects (NOAA/NWS)	Awaiting demonstration	NPOESS requirement for snow cover	Possible
Marine Productivity in Coastal regions (R2)	High spatial and temporal resolutions needed	NASA-SIMBIOS; Coastal bio-optics (NOAA, EPA)	Excellent	Possible NPOESS derived product	Active currently

Parameter/ Question	**Implementation Details**	***In Situ* Measurements**	**Technical Readiness**	**Operational Potential thru 2014**	**Partnership Potential**
Carbon Sources and Sinks (R2)	CO_2, CH_4 column mapping is most promising approach;	Flask network, buoys (NOAA), Ameriflux/Flux Net (DOE, USDA, NASA)	Experimental technique, needs further develop.	Not currently an operational requirement	Possible
Sea Surface Salinity (R3)	Very high radiometric precision needed for passive µwave observation	Ships and moored/drifting buoys (NOAA/NSF)	Approaching readiness (done from aircraft)	Unfulfilled NPOESS requirement; Aquarius Sensor	Likely with European Space Agency
Sea Ice Thickness (R3)	Significance of ice freeboard observations remains to be established	Moored buoys (ONR)	High spatial resolution radar; develop. needed	Desirable	Possible with domestic / international partners
Polar ice sheet velocity (R5)	Synthetic aperture radar interferometry; high latitude coverage (polar orbit) needed	GPS (NASA, NSF)	Demonstrated	Desirable	Possible
Ocean Surface Winds (C1)	Active µwave technique	ships, buoys (NOAA, WWW)	Demonstrated by NSCAT and SeaWinds	Yes	Seawinds cooperation with Japan; EUMETSAT
	Passive µwave radiometry / polarimetry to be demonstrated	N/A	Windsat/Coriolis demonstration funded by DOD, USN, NPOESS	NPOESS requirement may be fulfilled	Possible
Primary Productivity (C2)	Global 1 km or better resolution needed	NASA-SIMBIOS, GOOS, GTOS, crop, forest inventories (USDA, FAO), LTER (NSF)	Excellent	NPOESS requirement	EUMETSAT coordination
Coastal Region Properties and Productivity (C3)	Multispectral radiometry at high spatial and temporal resolution from GEO	Coastal observations (NOAA, EPA)	Excellent	Not currently	Possible
Deep Ocean Circulation (P3)	Requires *in situ* oceanographic observations	Ships and ARGO floats (NOAA, NSF)	WOCE, GODAE research projects provide initial data base	Operational Global Ocean Observing System is being envisaged	Multi-agency, international cooperation is anticipated